Tapping into the power of PlayStation2

Rethinking software design to exploit the cutting-edge technology of PS2.

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Topics

- Looking at the way PS2 works
- How that affects your software design
- Making effective use of GS drawing ability
- Utilising a micro-programmable graphics pipeline effectively
- Data handling for parallel processing

Designing PS2

- Requirements
  - Hardware is fixed for lifetime of machine.
  - High-quality graphics requires massive bandwidth to maintain pixel fill-rate
  - Huge calculation ability is required to transform and light large numbers of polygons
  - Large bandwidth is required for data such as geometry and textures

PS2 Design
Graphics Synthesizer

- Achieving Graphics performance
  - Embedded DRAM gives 48 GByte/sec memory bandwidth to eliminate pixel fill bottleneck.
  - Fill rate is 2.4Gpixel/sec for 32bit + Alpha + Z
  - Free alpha enables multi-pass effects
  - 1.2GByte/sec bandwidth main memory to GS for texture and geometry.

Pixel Fill Rate

PS2 Design - Vector Units

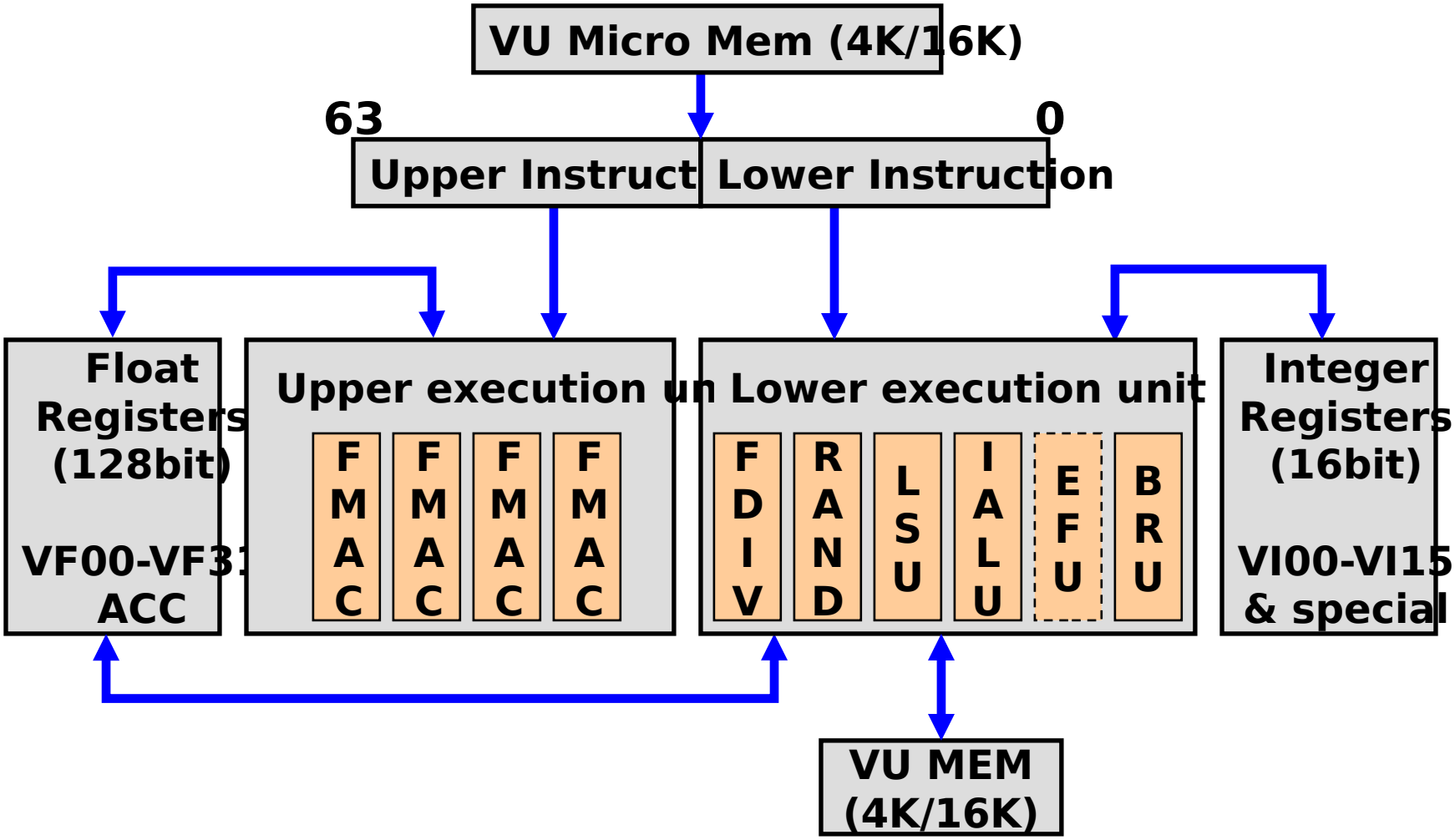
- Total 6.2GFlops including CPU FPU
- Twin geometry engines running @300mhz
- Optimised for 3D calculations
- Easy to develop pipelined programs
- VLIW run 2 instructions in parallel
- SIMD instructions run 4 FMACS in

PS2 Design
Geometry Performance

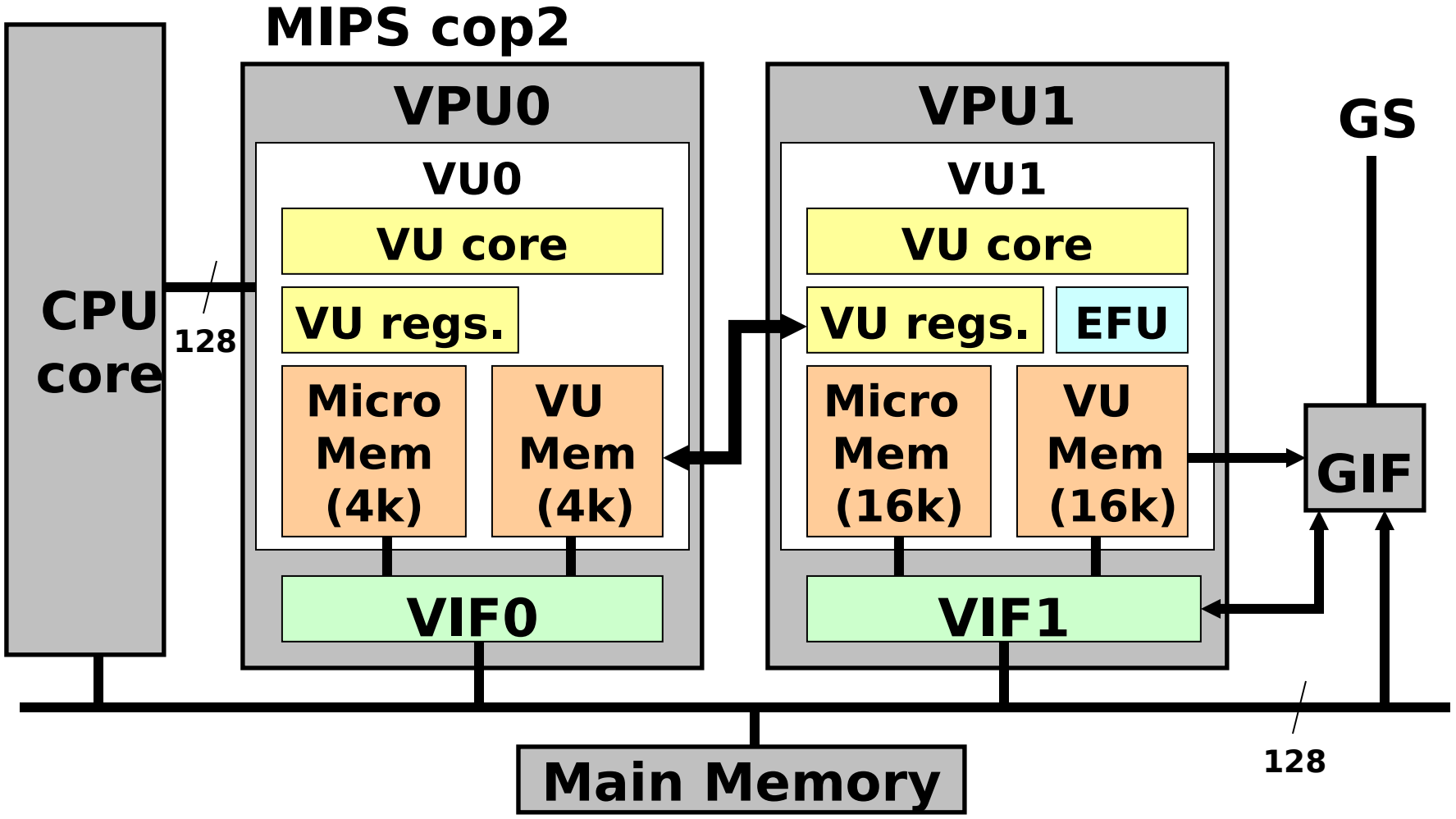
PS2 Design - Vector Units

- Vector Unit SIMD instructions (2 forms)
- Broadcast
  - X*bc, Y*bc, Z*bc, W*bc
  - (where bc is X,Y,Z,W)
- Normal
  - X*X, Y*Y, Z*Z, W*W
- There are also single cycle multiply and accumulate

PS2 Design - Vector Units



Vector System outline



PS2 Design - Vector Units

- Vector Unit 0
  - Available as a co-processor for CPU
  - More flexible calculation for dynamic data such as physics, animation
- Vector Unit 1
  - Direct path to Graphics Synthesiser
  - Very fast transformation

Vector Code

- SIMD single cycle vector multiply
- Apply matrix in 4 cycles (uses accumulator)

```
MUL ACC, vector1, vector5x
MADD ACC, vector2, vector5y
MADD ACC, vector3, vector5z
MADD vector6, vector4, vector5w
```

- Alternatively use the 4 FMACs to perform parallel calculations eg. 4 lights.

Vector Code Example Parallel dot product

- Store normals across vectors

  Vector 1 = (nx1, nx2, nx2, nx3)

  Vector 2 = (ny1, ny2, ny3, ny4)

  Vector 3 = (nz1, nz2, nz3, nz4)

  MULL ACC, Vector1, Vector1

  MADD ACC, Vector2,Vector2

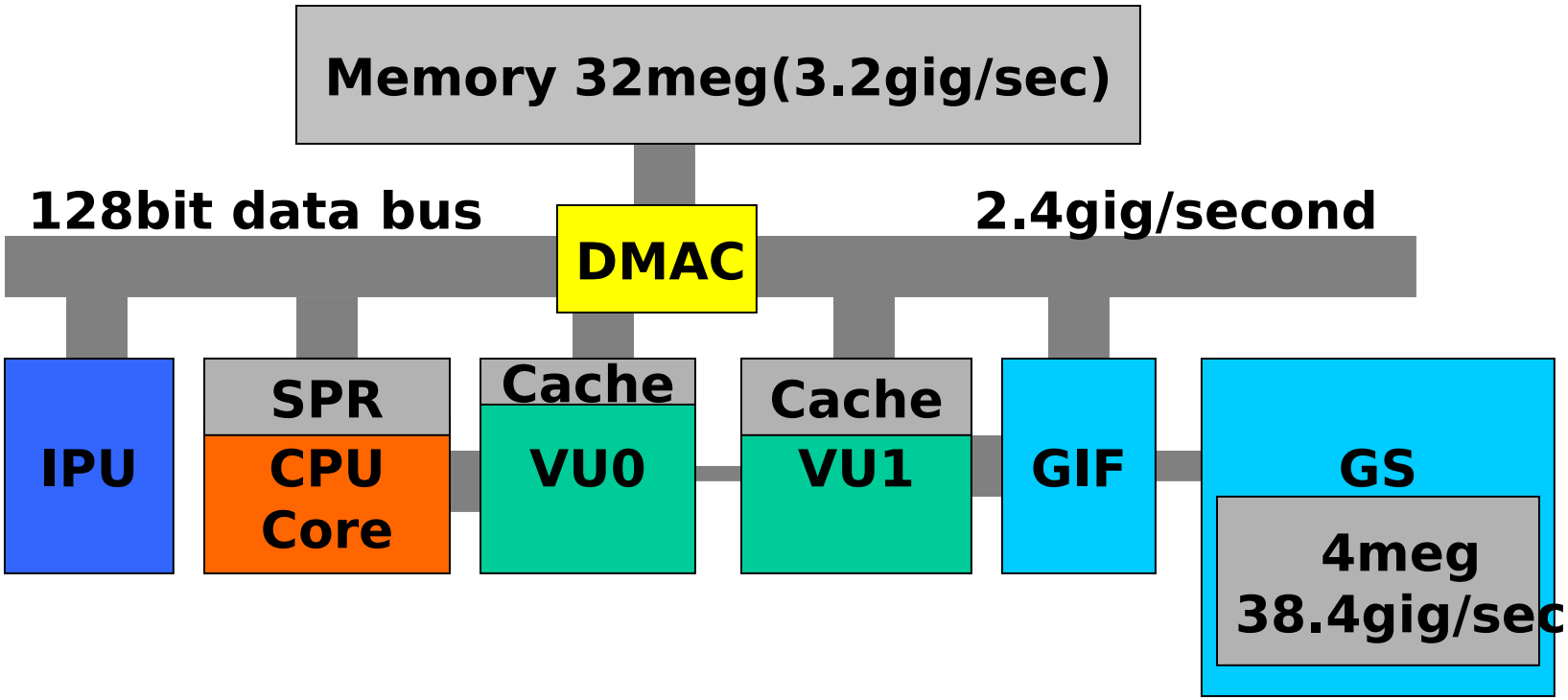
  MADD result, Vector3,Vector3

- Result is 4 dot products stored in x, y, z, w

PS2 Design - DMA System

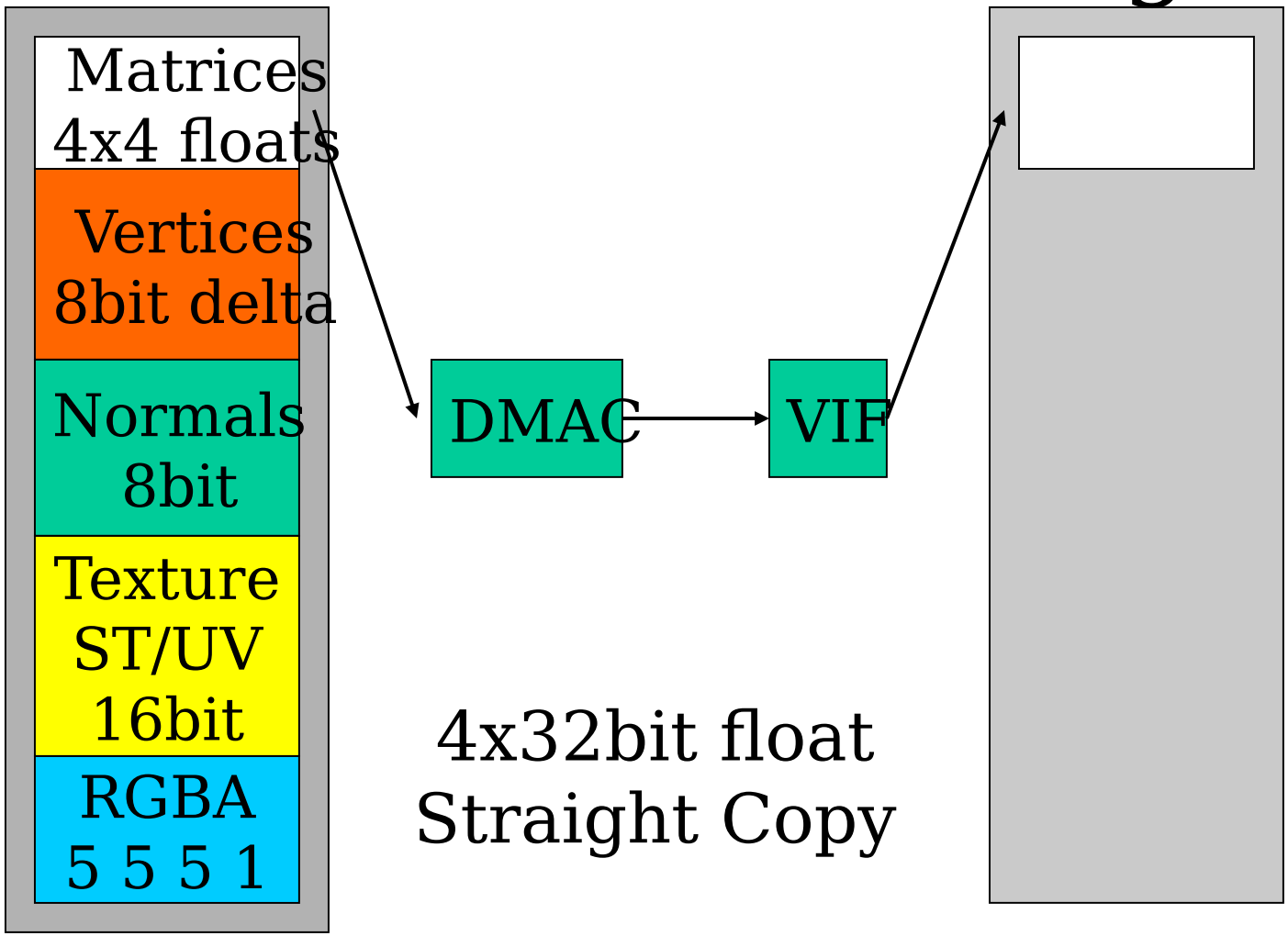
- Data handling
  - 128bit bus provides 2.4GByte/sec bandwidth to devices
  - Additional 128bit connection VU1 to GS
  - DMA intelligent data transport frees CPU
  - Image decompression unit
  - Geometry decompression: delta + unpack

PS2 data handling

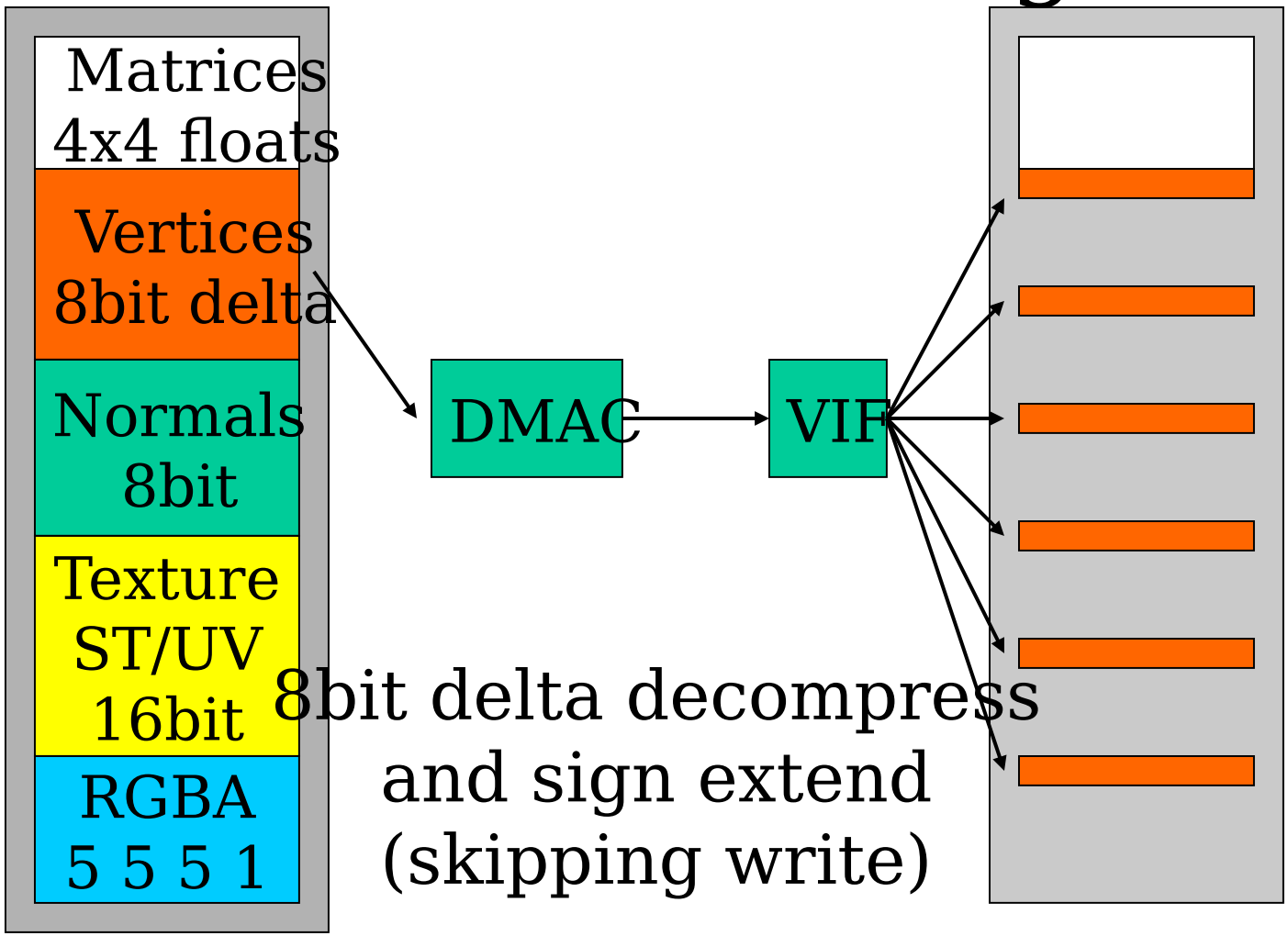


rid UMA = 40 meg/frame can be transferred between devic
lligent DMA handler completely frees CPU

PS2 Data handling

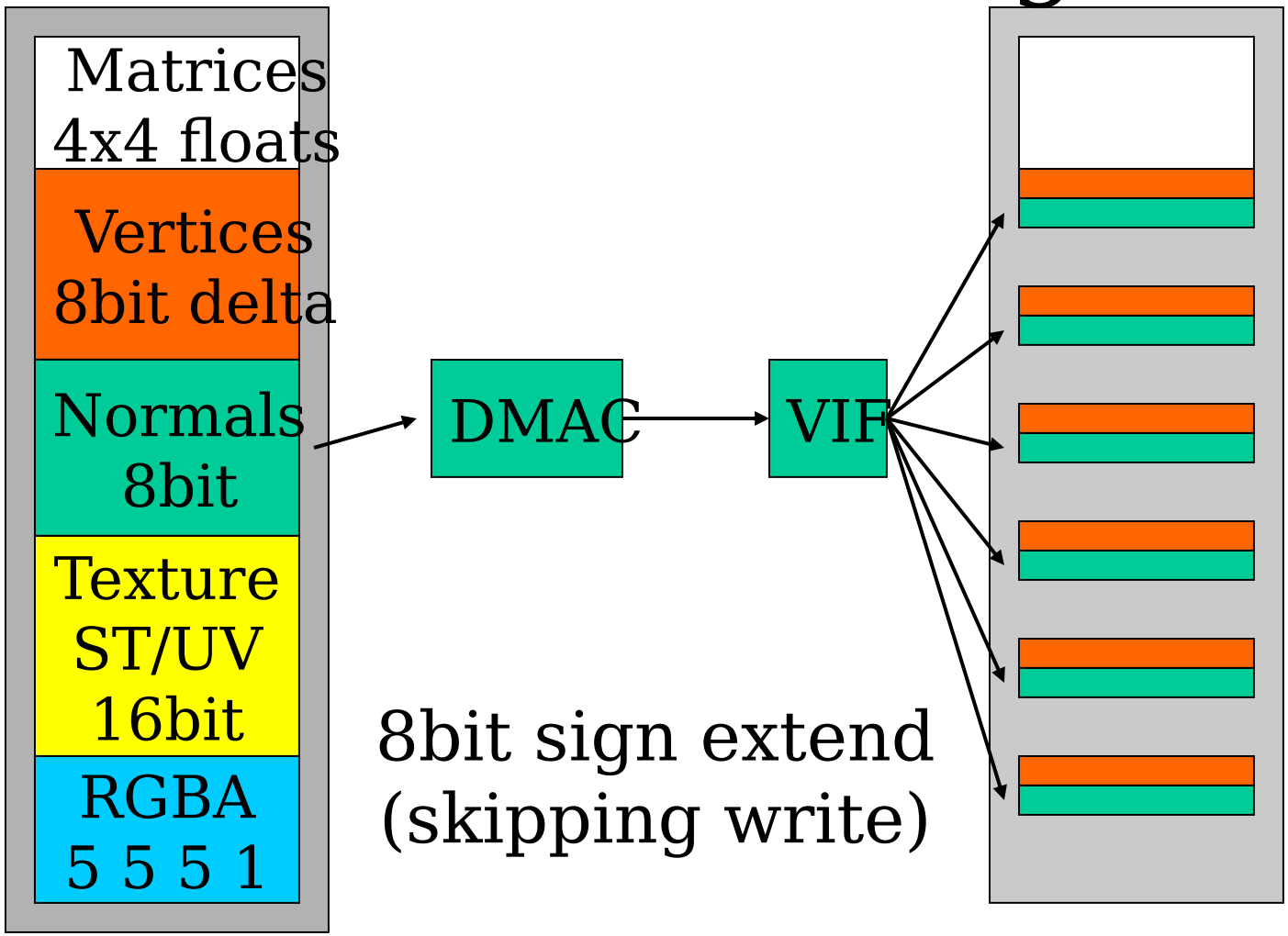


Data Handling

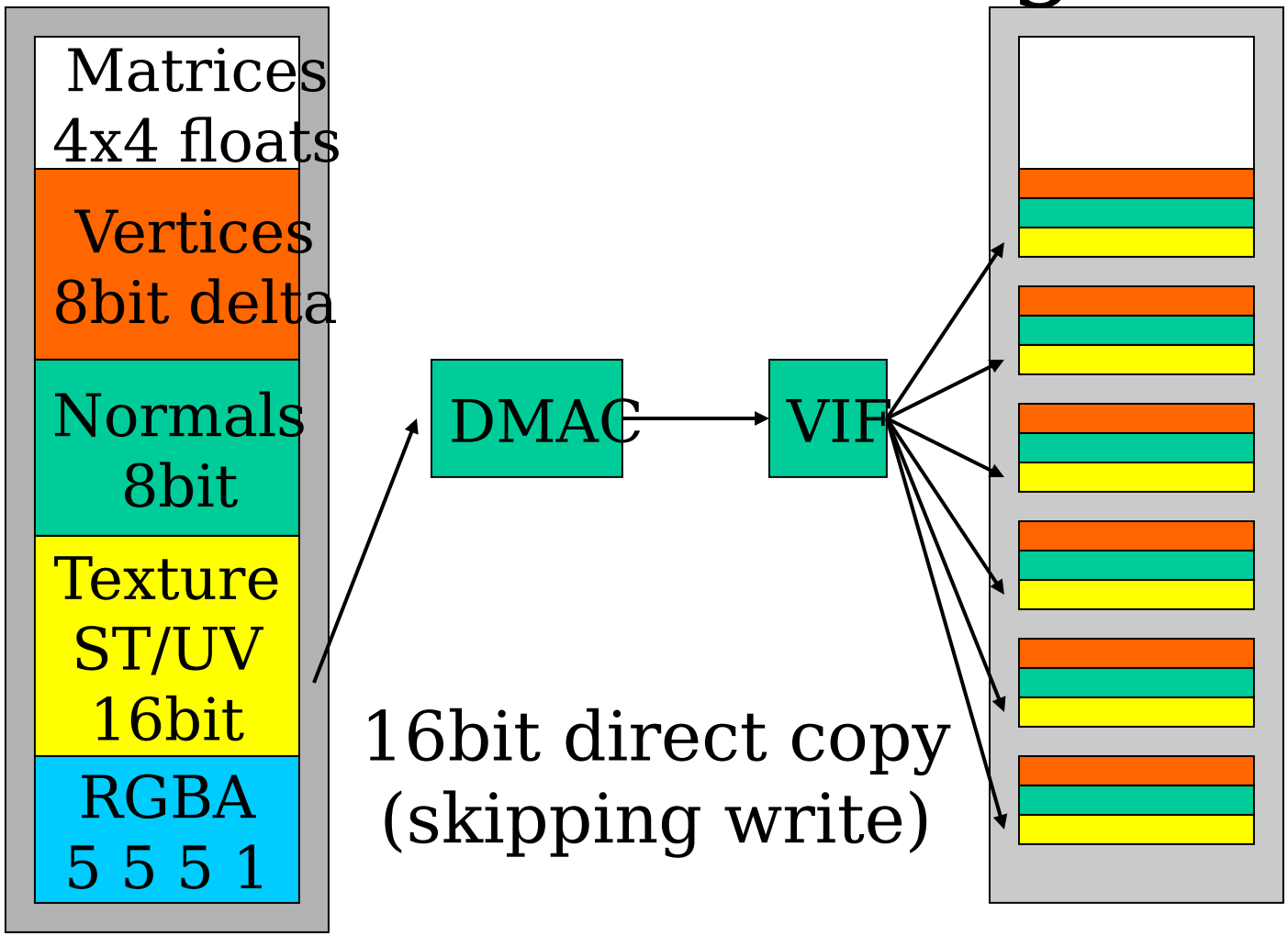


8bit delta decompress
and sign extend
(skipping write)

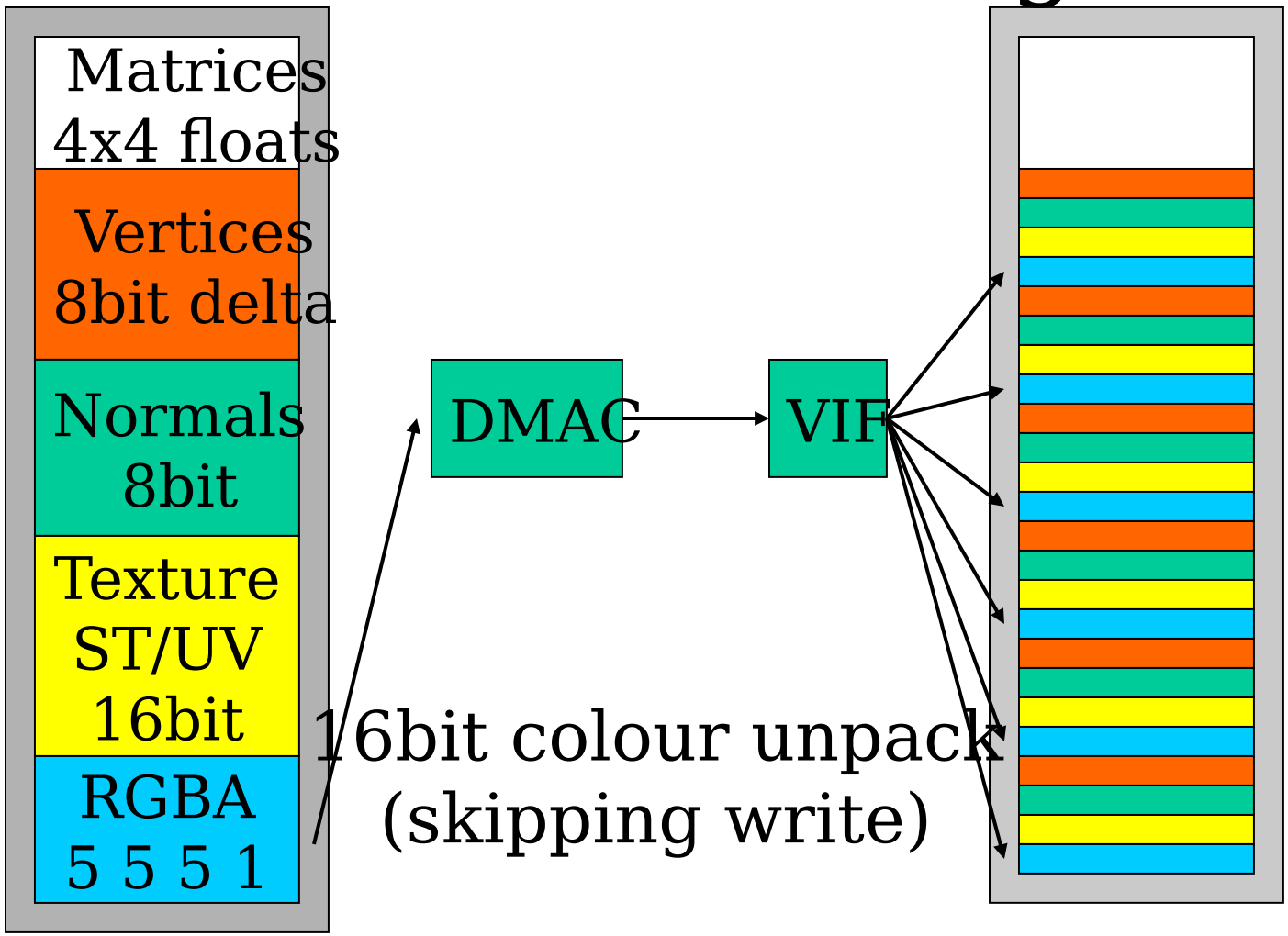
Data Handling



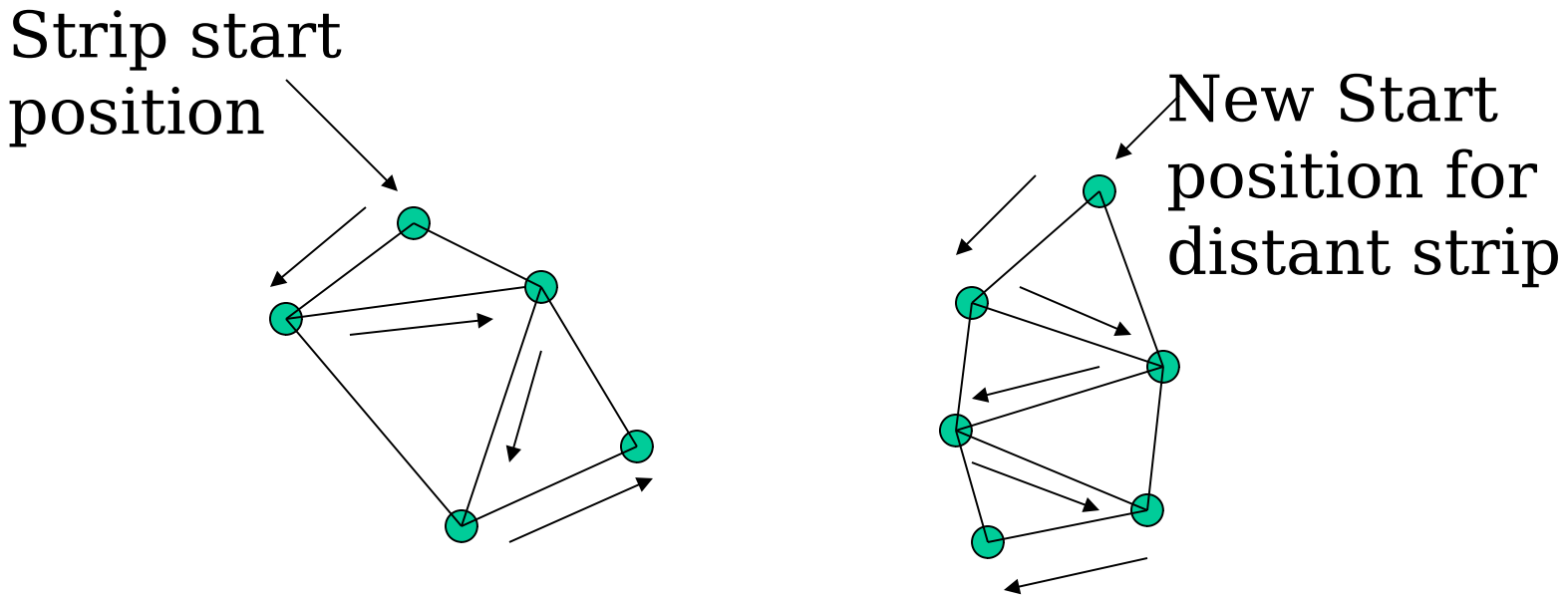
Data Handling



Data Handling



Delta Decompression

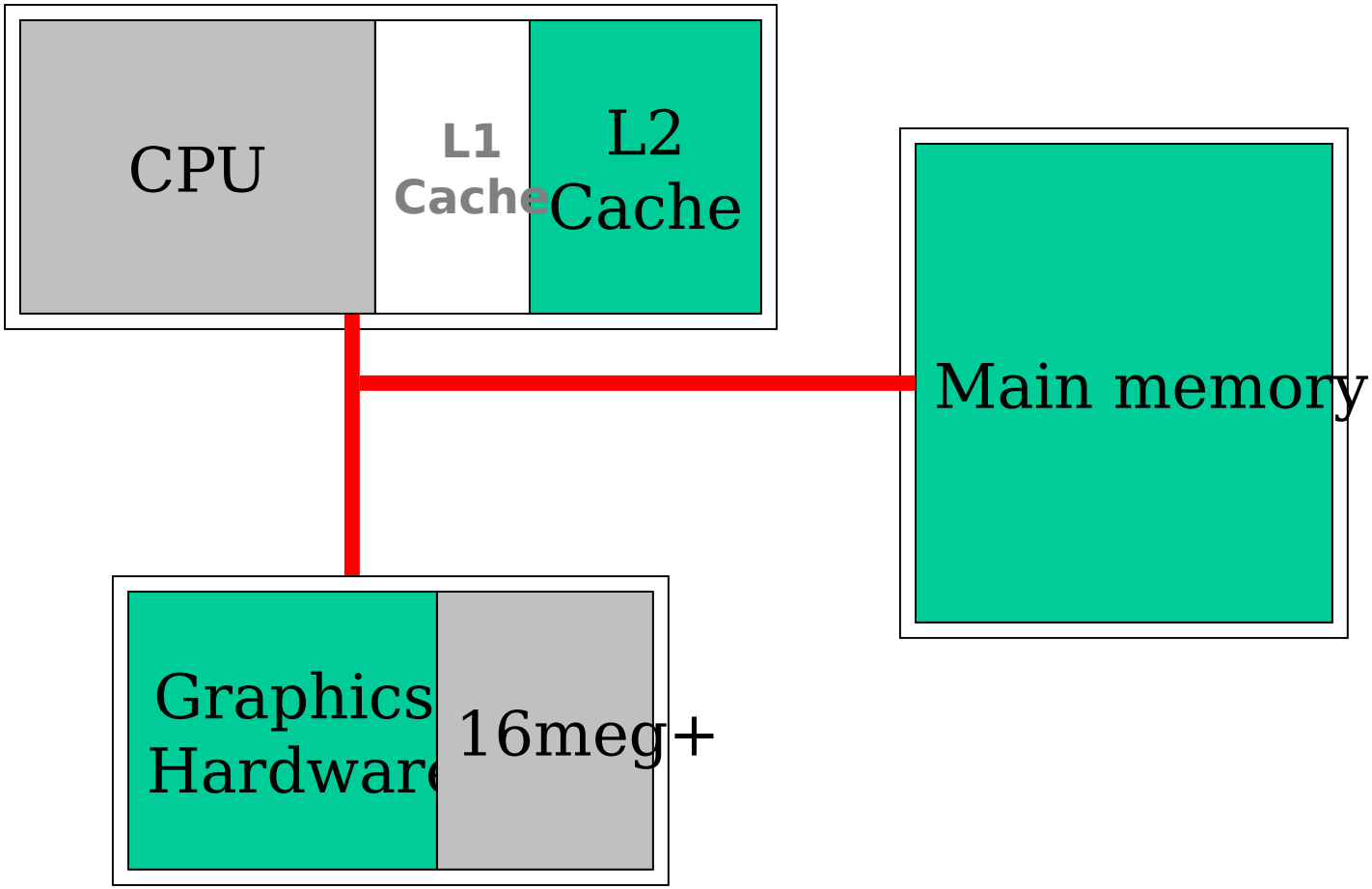


- Points in a strip tend to be close together so delta is useful.
- After the start position each point is offset from the previous position.
- This packs vertex from 12 bytes for 3 floats down to 3 bytes

Cache usage

- Features of cache
  - High speed memory
  - Expensive
  - Maintains CPU speed for data already in cache
- Dynamic media such as geometry does not stay in the cache for any length of time so large cache is unhelpful.
- Data throughput is more

Simplified PC architecture



PC games design

- PC has large cache but poor bandwidth
  - Big indexed meshes
  - Extensive culling and clipping to reduce bandwidth to graphics card
  - Textures cached in Graphics card ram for speed
  - Higher resolution and good monitors require high resolution textures
- This doesn’t work well on PS2!

PS2 Game

- PS2 has good bandwidth and small caches to buffer DMA
  - Enables on the fly texture downloading
  - Extra DMA geometry compression is available
- Vector units enable alternative efficient model representations
  - Procedural models / patches
  - Micro-models

1st generation PS2

- Fighting small CPU cache,lack of VRAM
- Existing game with bigger textures
- Poly counts upped on models.
- Basic VU1 Directional lighting / Prelit
- Recompiled PC or PS1 code
- Minimal post processing

2nd generation PS2

- Working with the memory system
  - Maximising DMA use
  - Using efficient data representations
- Exploiting the architecture of micro programmable graphics pipeline
  - Many different types of renderers
- Using GS fill rate
  - Enhanced graphics effects

Examining GS chip

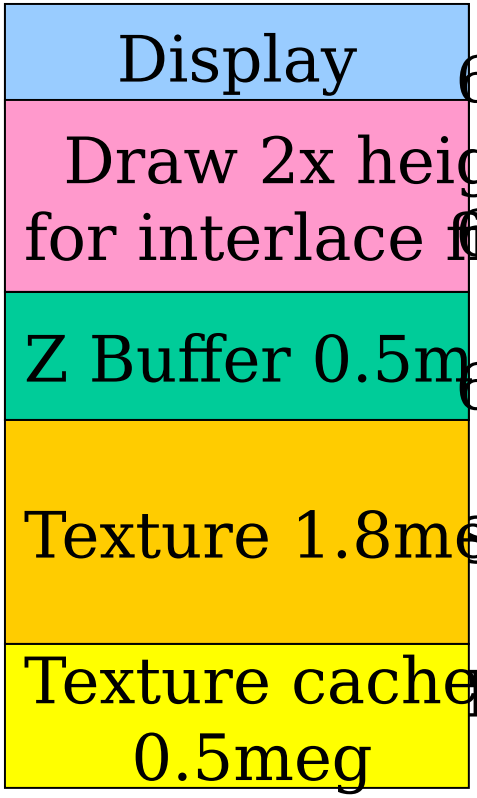
- Huge bandwidth and fill rate
- Very fast alpha blending
- Setup time is the limitation to poly counts
- Always use strips
- Designed for TV
  - Note (640x256*50=8mil pixel/sec)
- Use the high poly count with multi-pass

Using GS effectively

- Use multi-pass (alpha is free) and saves on vertex re-calculation
- Strips offer a huge saving over triangles
- Keep polygons small - many small polys are much quicker than one large polygon.
- Penalty on miss is not huge.
- Texture tiling and wrap modes

Suggested VRAM arrangement

- For 60hz frame-rates



640x224x24bit = 430k

640x448x24bit = 860k

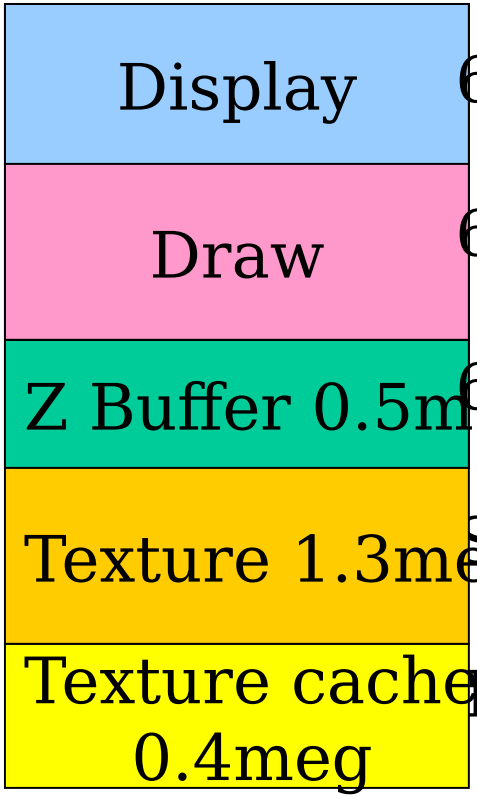
640x448x16bit = 573k

Static textures = 1.8meg

Texture cache=8*256x256 (8bit)

Suggested VRAM arrangement

- For <60hz frame-rates



640x448x24bit = 860k

640x448x24bit = 860k

640x448x16bit = 573k

Static textures = 1.3meg

Texture cache=6*256x256 (8bit)

Using GS effectively

- 640x448 is maximum visible pixels per frame with 2 sample / pixel full screen filter
- Assuming fairly inefficient MIPMAP and multi-pass using 20 texels per pixel at 8bit = 6meg
- With 2meg static texture and 4meg/frame DMA this leaves 16meg geometry bandwidth
- Savings can be made with tiling and multiple passes with 4bit textures

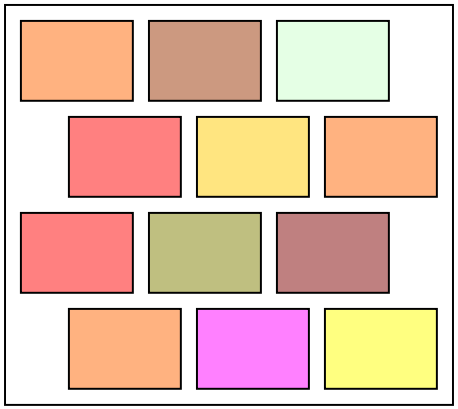
Paletted textures

- Efficiency of paletted texture improves with size
- Quality of paletted texture degrades with size
- For 256 colour pallet minimum 16x16 useful size (all colours used). 256x256 still good
- For 16 colour pallet minimum 4x4 useful size. Works well for

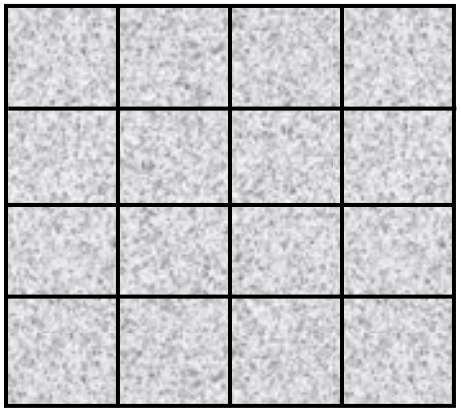
Paletted textures example
Only 4bit pallet!

Using GS effectively

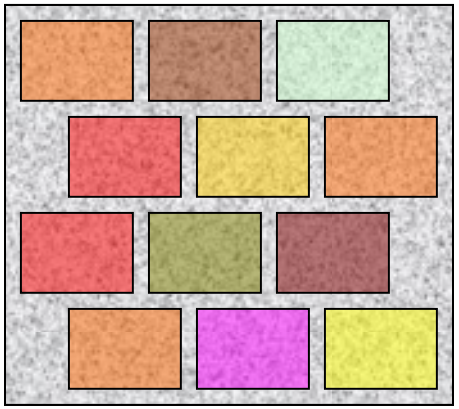
- Improving texture detail (2 layers)



Texture 1(4bit)
128x128x4bit=8k



Texture 2(Tiled)
64x64x4bit=2k



Texture 1*Texture 2
256x256x24bit = 196k

he result is 10k versus 196k = nearly 20:1 saving

GS Effects

- Smoke, Fire
- Motion Blur
- Focus effects
- Heat haze
- Anti aliasing
- Interlace blending

GS Effects : Smoke, Fire

- Use particle emitter to render off screen
- Alpha blend large percentage of previous sprite
- Use scale and translate to create drift
- Add ‘noise’ to emitter position to create lifelike effect

GS Effects : Motion Blur

- Draw new screen
- Copy on top with transparency the previous frame
- Effect is adjusted by alpha value
- Fill rate easily allows this during the Vertical Blank

GS Effects : Depth of field

- Draw new screen into off screen buffer
- Copy to display buffer
- Sprite copy screen with scale to display buffer using Z test
- Repeat for different depths

GS Effects : Heat Haze

- Draw new screen into off screen buffer
- Create mesh of squares texture mapped to draw buffer
- Copy squares to display with texture coordinate offsets based on sinusoidal functions & time
- Display distorts like heat haze

GS Effects : Interlace blending

- Odd and Even lines are drawn alternately.
- Any image not drawn on both lines flickers.
- Scan-line blending solves the problem.
- Techniques to fix this
  - GS blend circuits with interlaced buffers(free)
  - Motion blur 0% of previous field(low

GS Effects : Anti-aliasing

- Hardware edge anti-aliasing.
  - Requires sorted polygons but looks excellent.
- Full screen anti-aliasing
  - Render to large draw buffer then use bi-linear filter to blend pixels smoothly.
  - Render 4x with 25% alpha and 1/2pixel offset in 4 directions. Same effect without the VRAM hit

PS2 parallel geometry pipelines

- You have to use Vector Units for good performance
- Many games don’t use them both effectively
- These are very flexible : sub-div surfaces, patches, terrain etc
- Micro-models
- Procedural models / Bezier patches

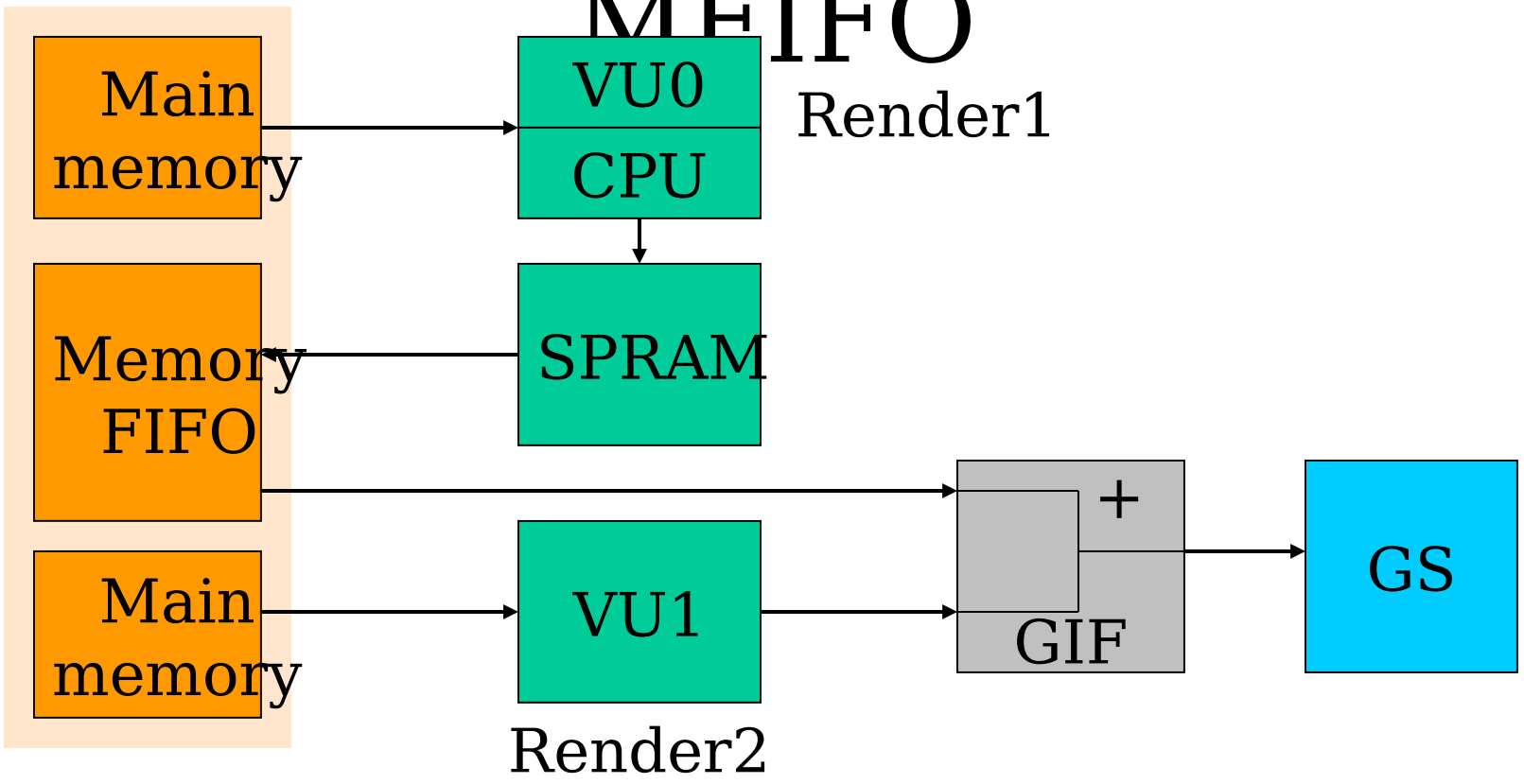
Using VU effectively

- Use many renderers (clipping/non clipping)
- Reuse vertices (micro-mesh / patch)
- Remember polys = 300MHZ/(cycles per vertex) so keep the VU busy every cycle
- Use them both!
- Pack your data

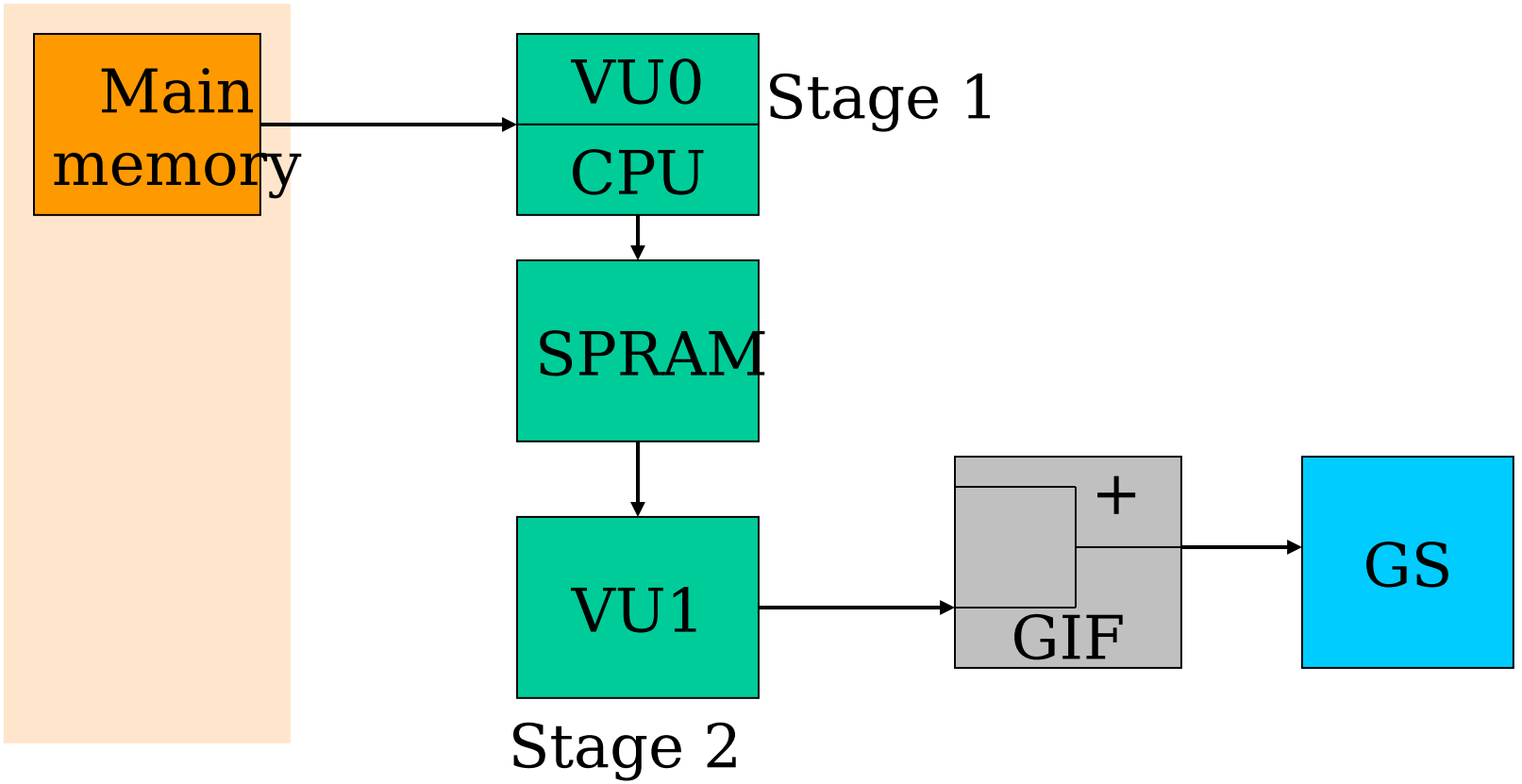
Vector Unit Optimisations

- Remember
  - Vertices = Clock speed/number of cycles
- Removing latencies
- Prologue, Epilog, Rolling up loops
- Vertex reuse
- Short vs Long loops

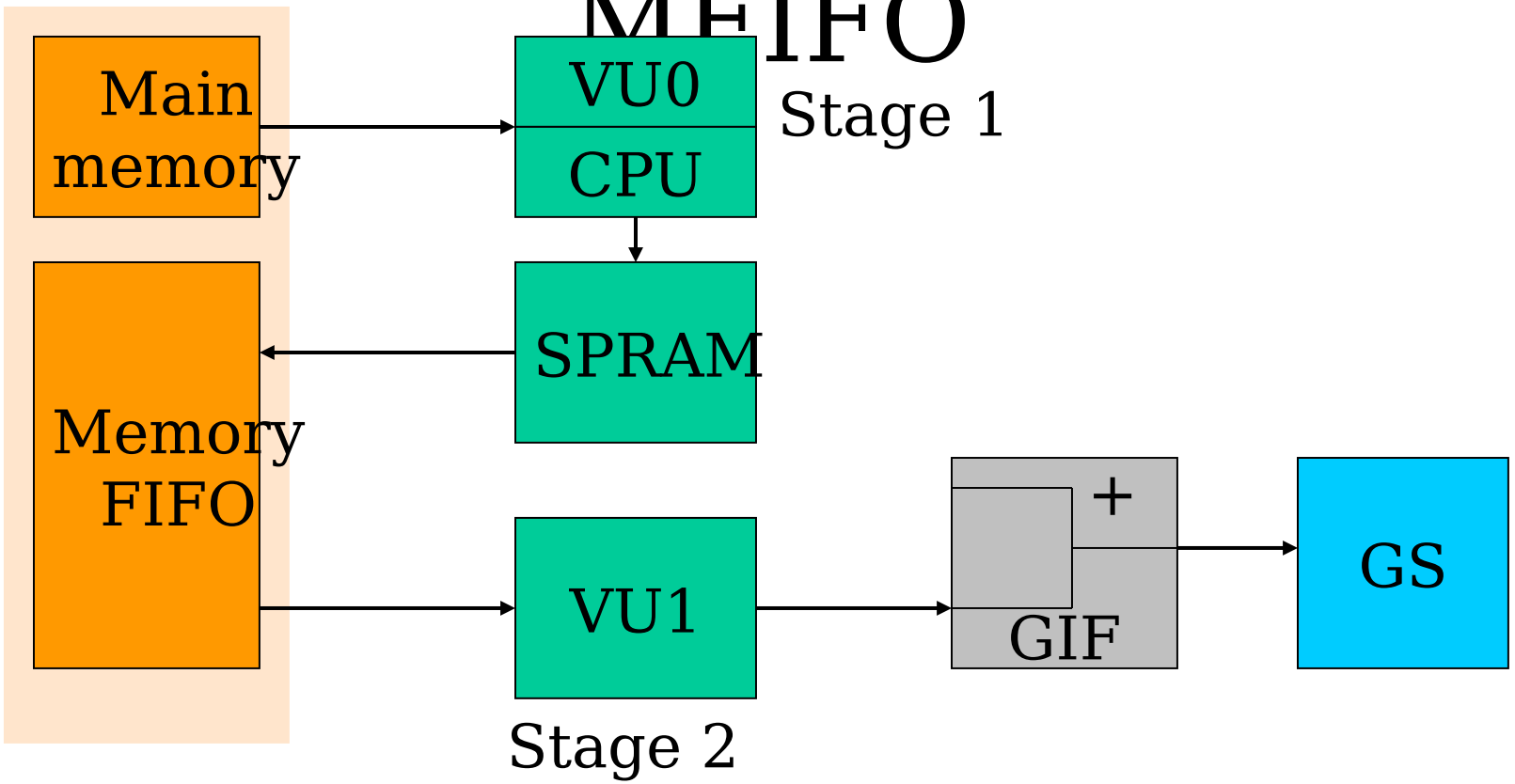
Using Vector Units Together
Parallel connection + MFIFO



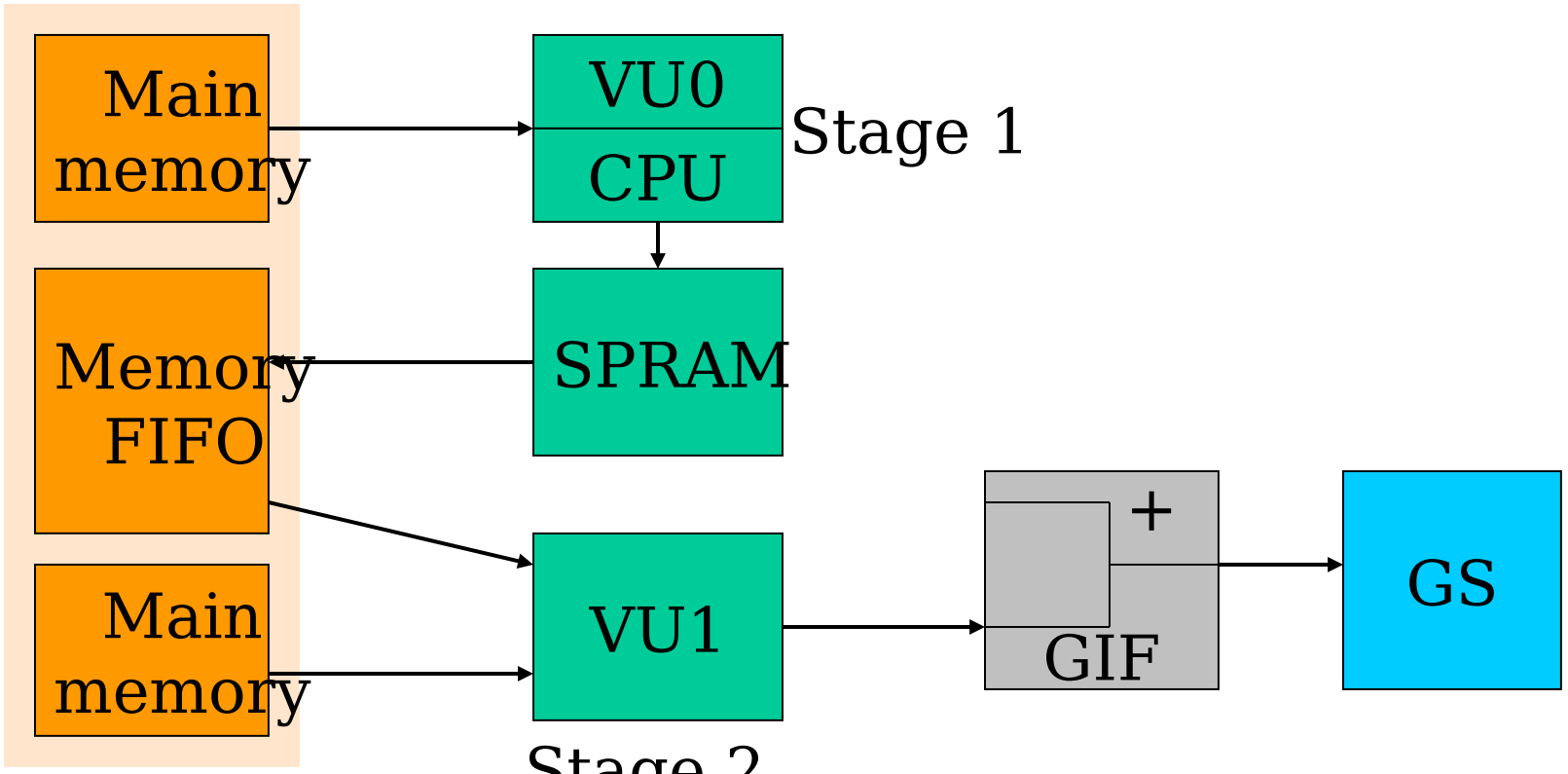
Using Vector Units Together
Serial connection 1



Using Vector Units Together
Serial connection 2 + MFIFO

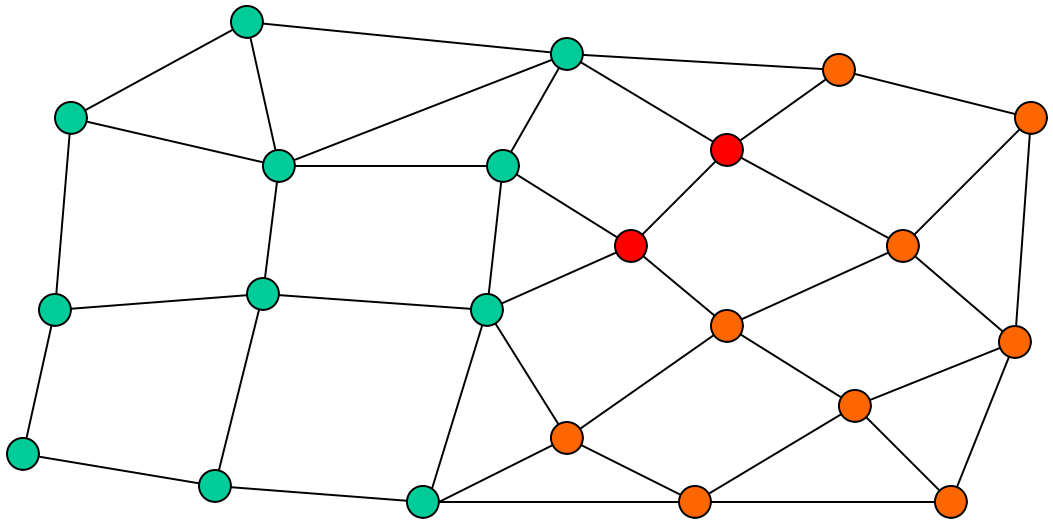


Using Vector Units Together
Serial connection 3



Micro Models

Most models can be separated into patches of point
These share vertices, normals and a common textu
Vertex reuse improves rendering efficiency
This allows more complex lighting models



Micro models

- Vertex cache
  - Divide model into patches using shared vertices
  - DMA set of vertices
  - Transform vertices
  - Indices used to generate triangle strips
  - Aim to achieve more than 1 triangle per vertex
- Circular FIFO style vertex cache

VU procedural renderers

- High efficiency vertex reuse
- Free bandwidth
- Wheels, spheres,
- Trees
- Terrain
- Bezier patches
- etc etc

VU deformers

- Displacement maps
- Random displacement
- Time based deformation
- Noise functions
- Texture warping

Conclusion

- Code with the system not against it
  - DMA is the key
  - Keep the Vector Units busy
  - Use that fill rate!
- The results can be excellent if the system is used well